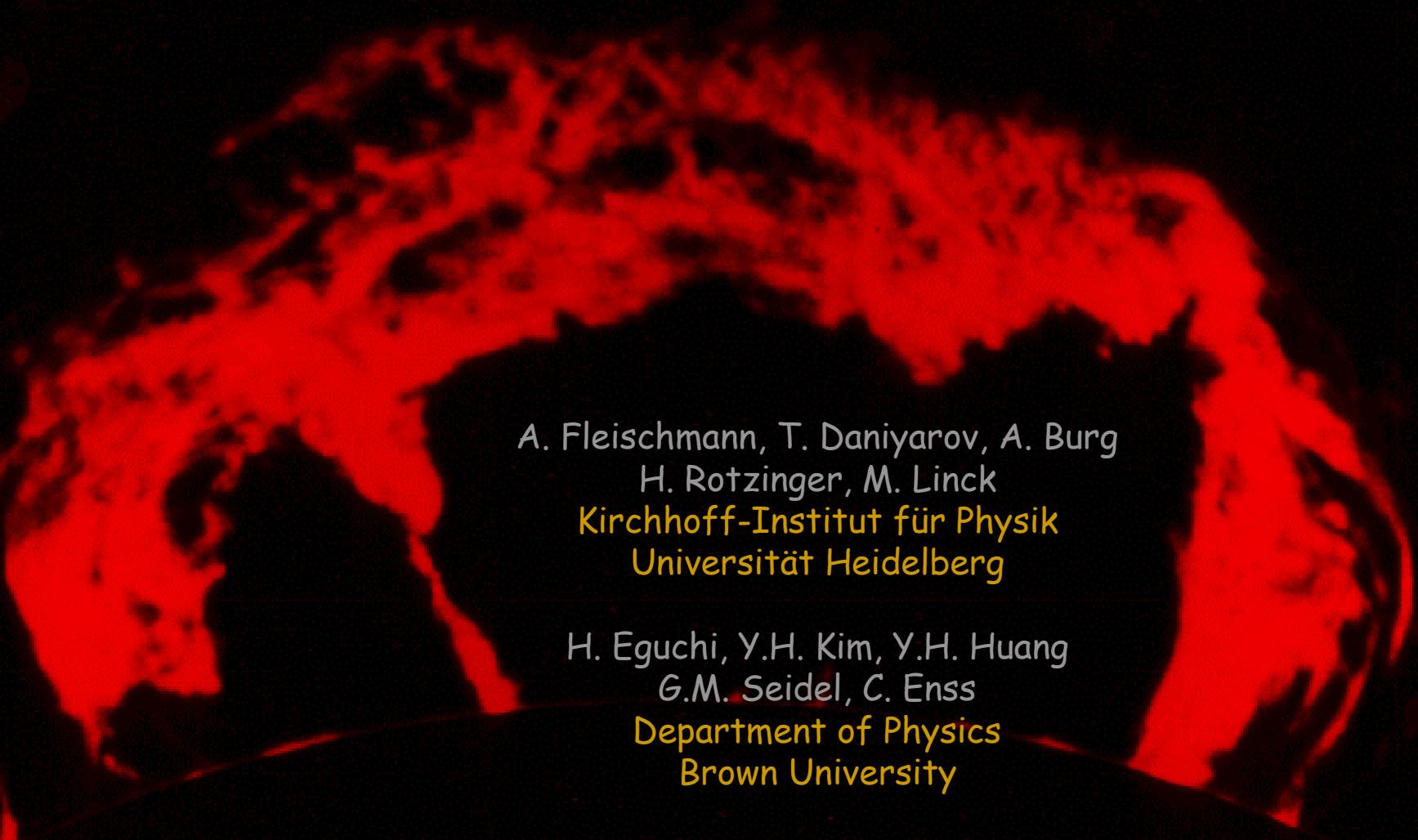


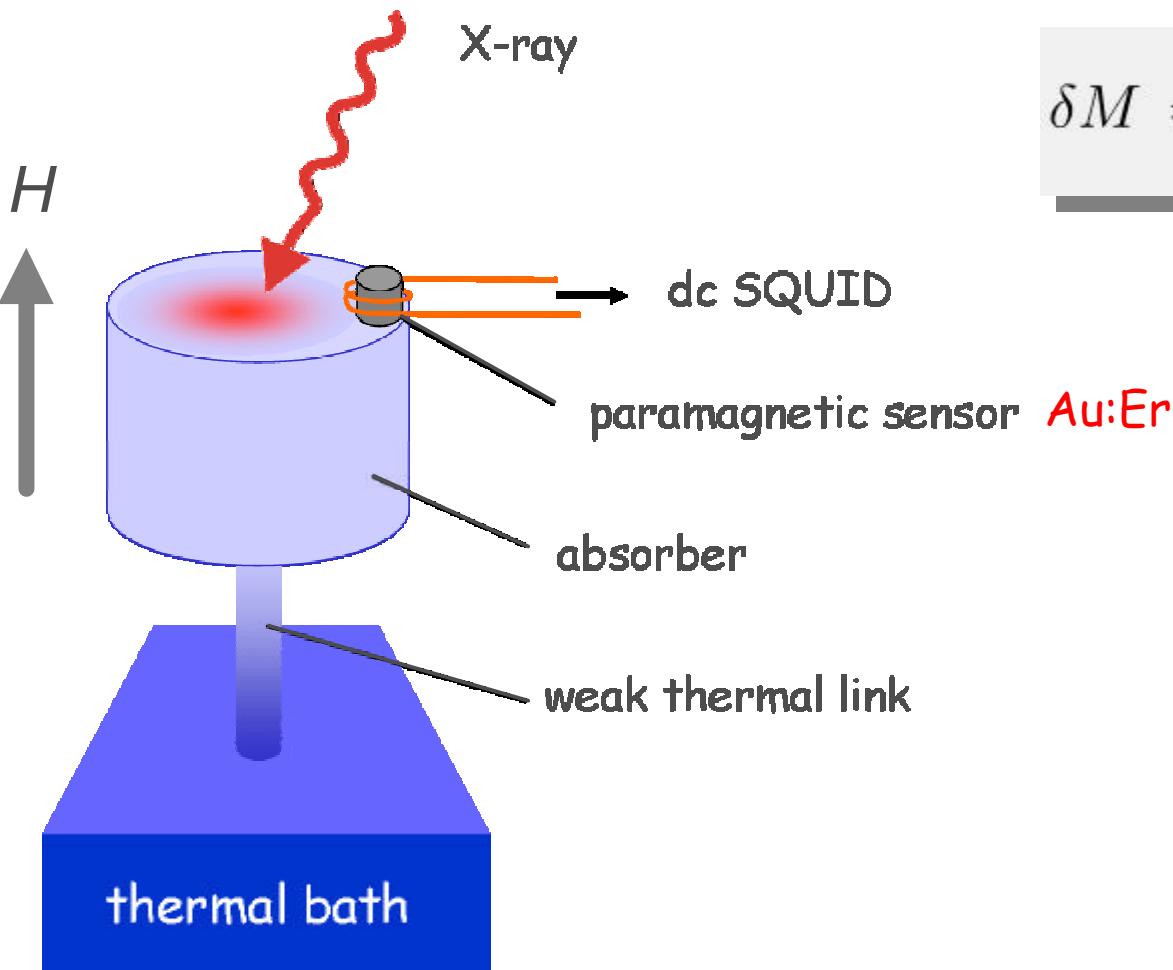
Metallic Magnetic Calorimeters Status of Development and Prospects



A. Fleischmann, T. Daniyarov, A. Burg
H. Rotzinger, M. Linck
Kirchhoff-Institut für Physik
Universität Heidelberg

H. Eguchi, Y.H. Kim, Y.H. Huang
G.M. Seidel, C. Enss
Department of Physics
Brown University

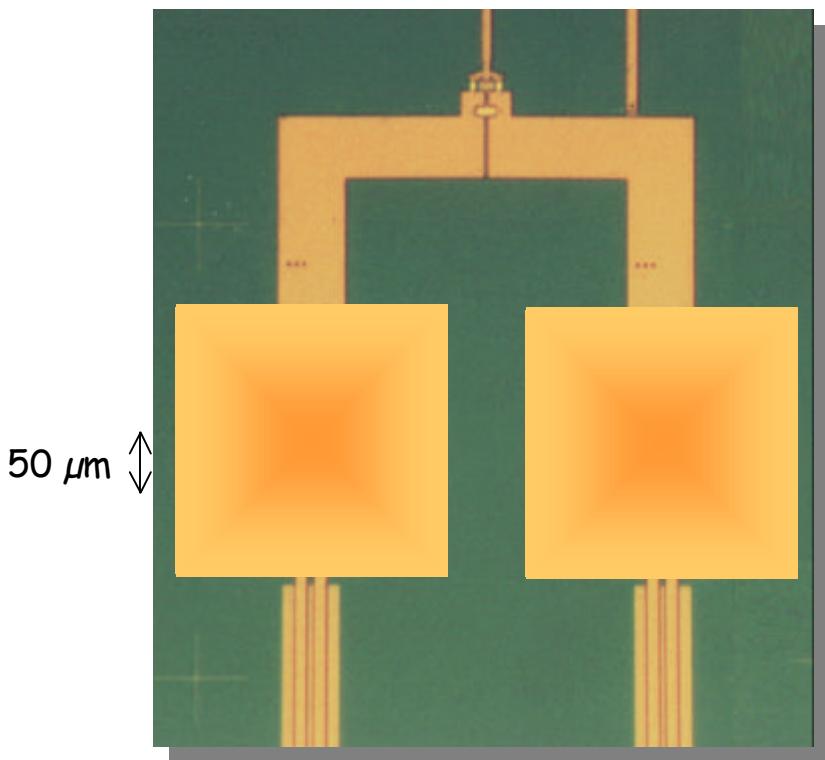
Metallic Magnetic Calorimeter



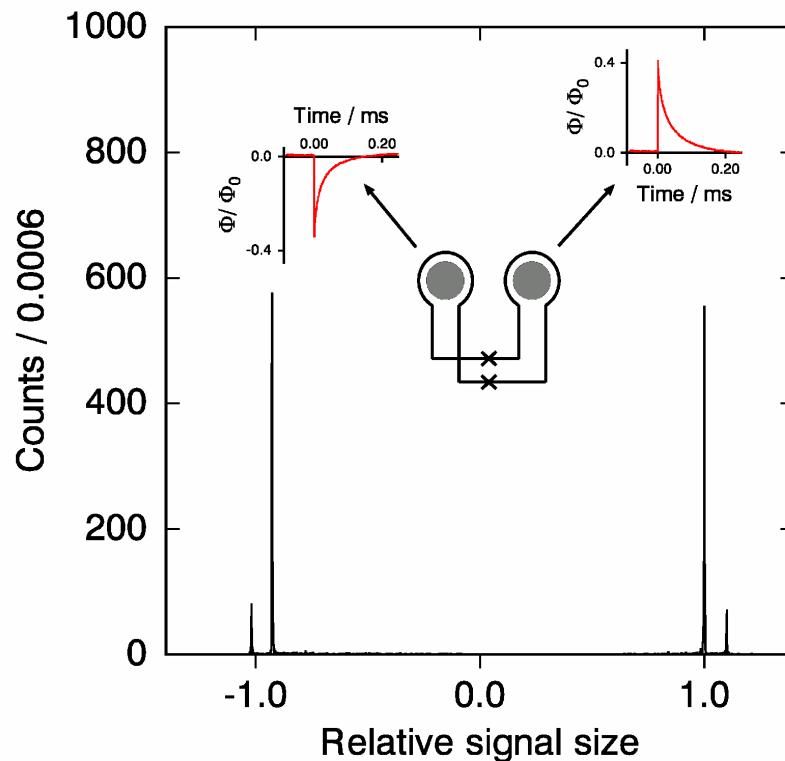
$$\delta M = \frac{\partial M}{\partial T} \delta T = \frac{\partial M}{\partial T} \frac{E_\gamma}{C_{\text{tot}}}$$

$$\tau = \frac{C_{\text{tot}}}{G}$$

Gradiometer With Two Sensors: Two-Pixel Detector

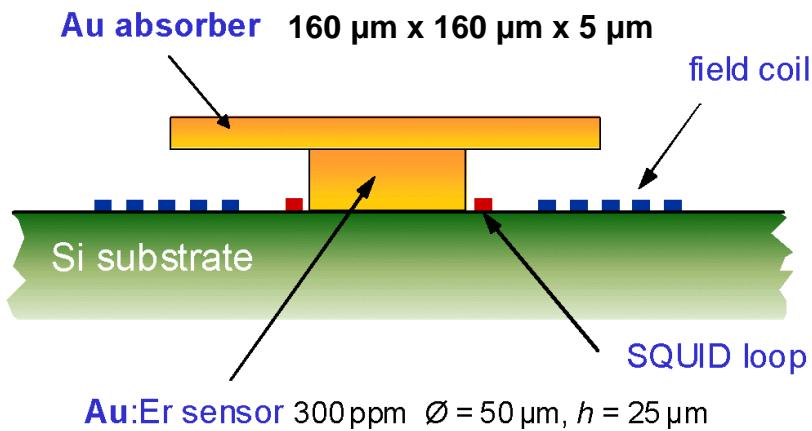


commercial SQUID chip
M.B. Ketchen, IBM 1992



performance of pixels almost identical

MMC Detector May 2003

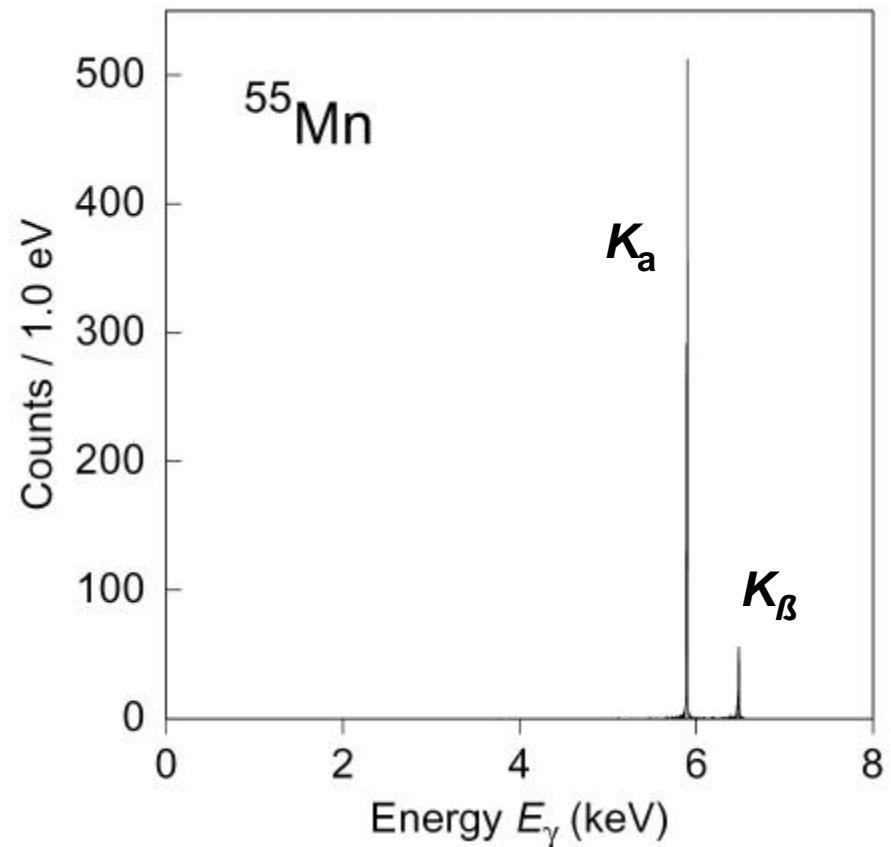


two Au:Er 300 ppm sensors

Gold absorber: $160 \times 160 \times 5 \mu\text{m}^3$

Heat capacity corresponds to a
Bi/Cu absorber of $250 \times 250 \times 28 \mu\text{m}^3$

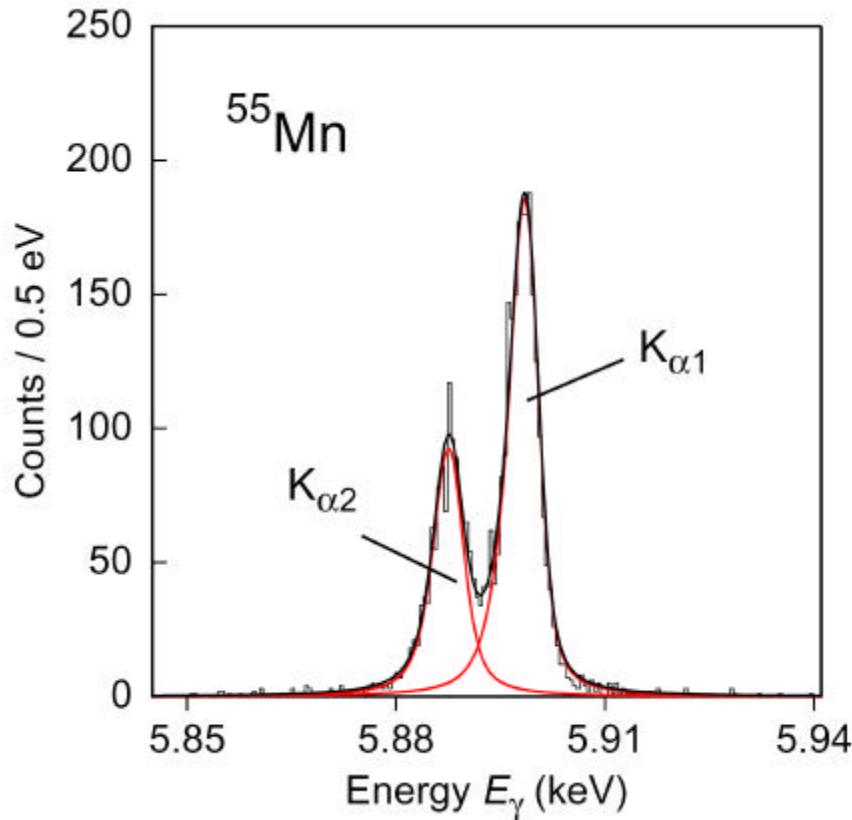
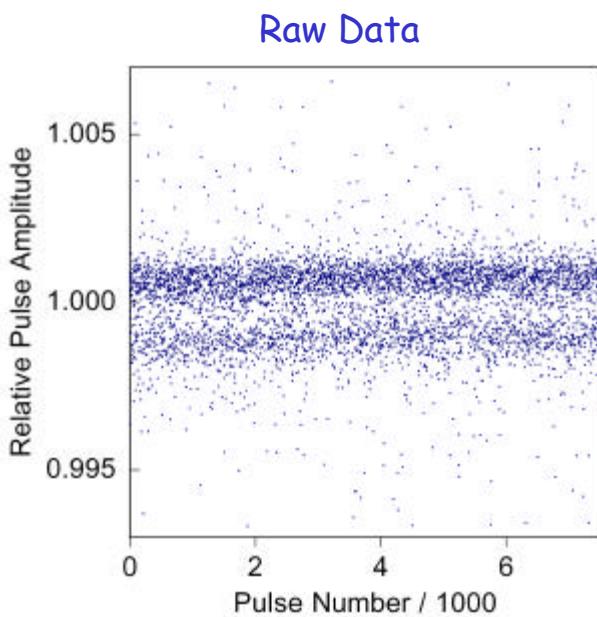
→ clean spectrum



Resolution: K_{α} -Line ^{55}Mn

two Au:Er 300 ppm sensors

Gold absorber: $160 \times 160 \times 5 \mu\text{m}^3$

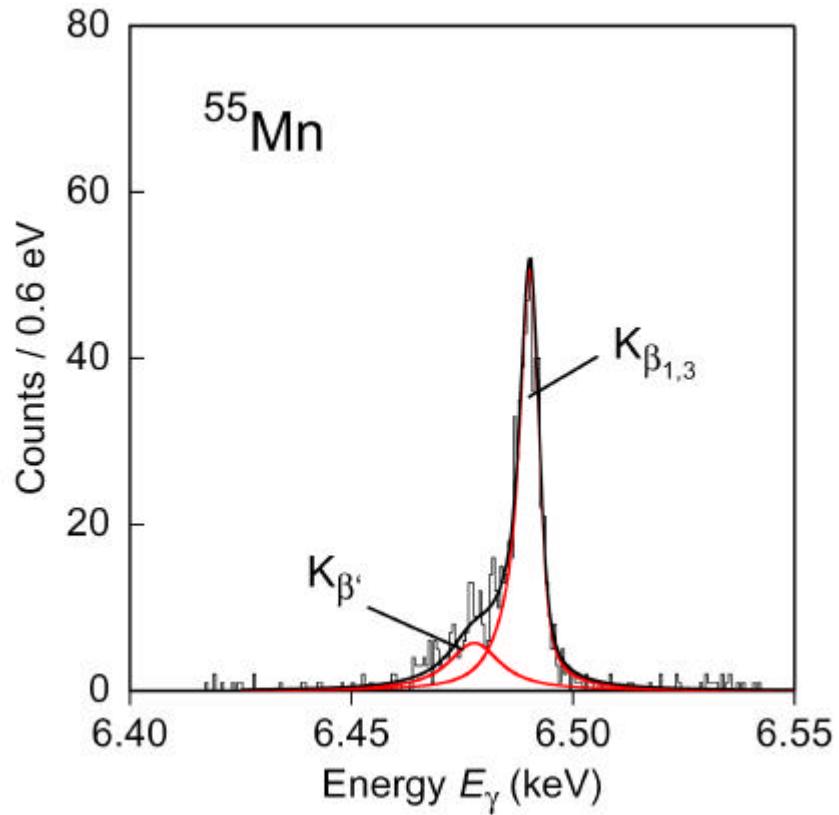
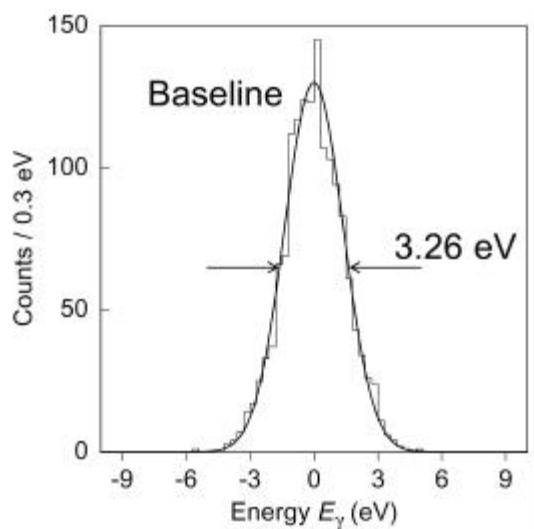


energy resolution 3.4 eV

Resolution: K_{β} -Line ^{55}Mn

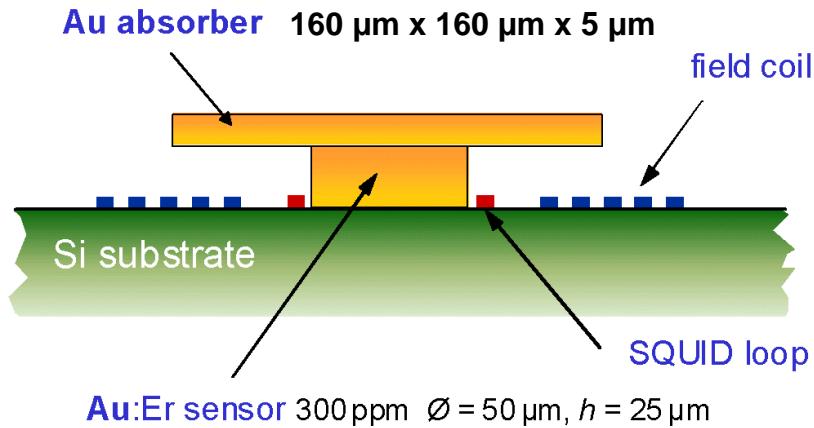
two Au:Er 300 ppm sensors

Gold absorber: $160 \times 160 \times 5 \mu\text{m}^3$



energy resolution 3.4 eV

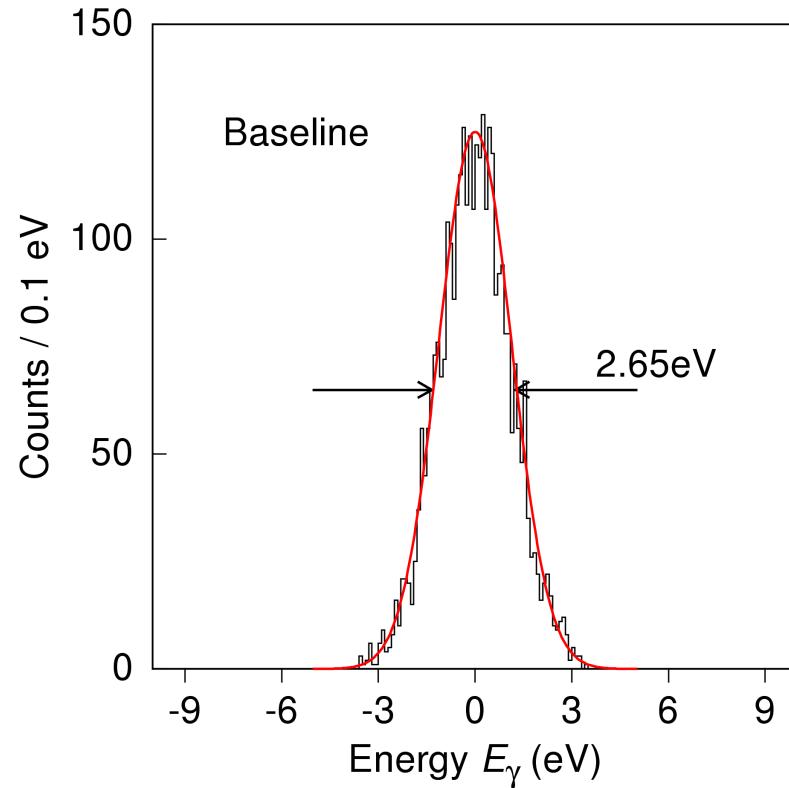
MMC Detector October 2003



one Au:Er 300 ppm sensors

Gold absorber: 160 x 160 x 5 μm^3

shielded SQUID junctions



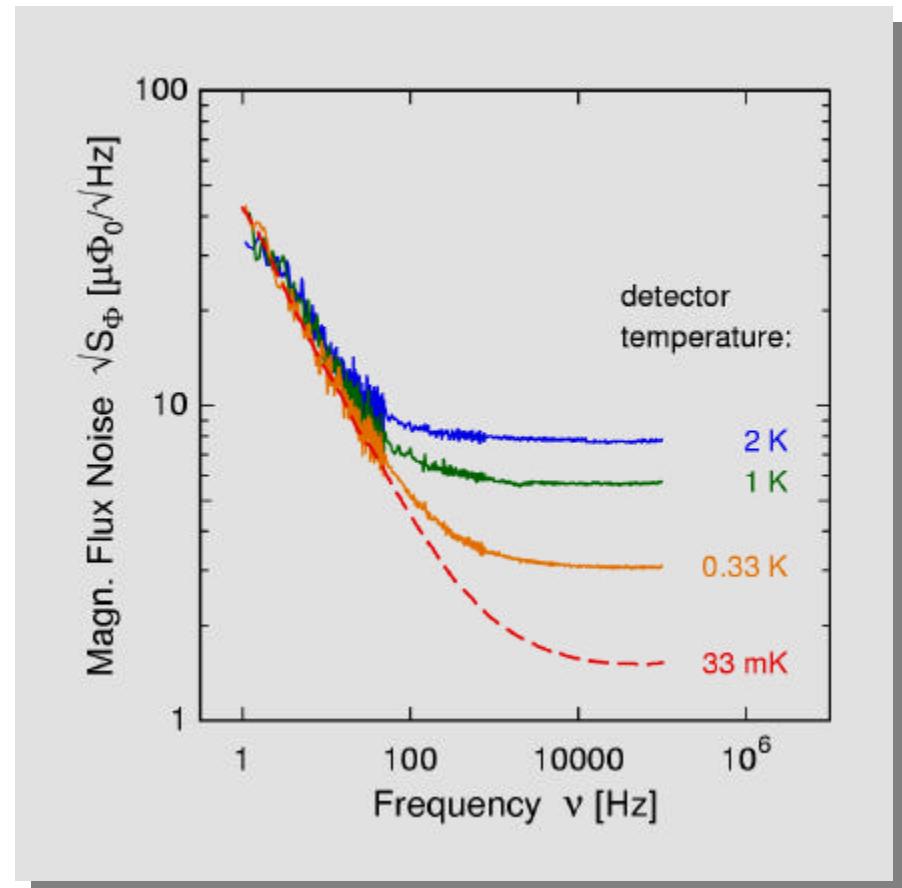
Thermal fluctuations in the cryostat broadened the spectrum: resolution 3.5 eV

Additional 1/f Noise

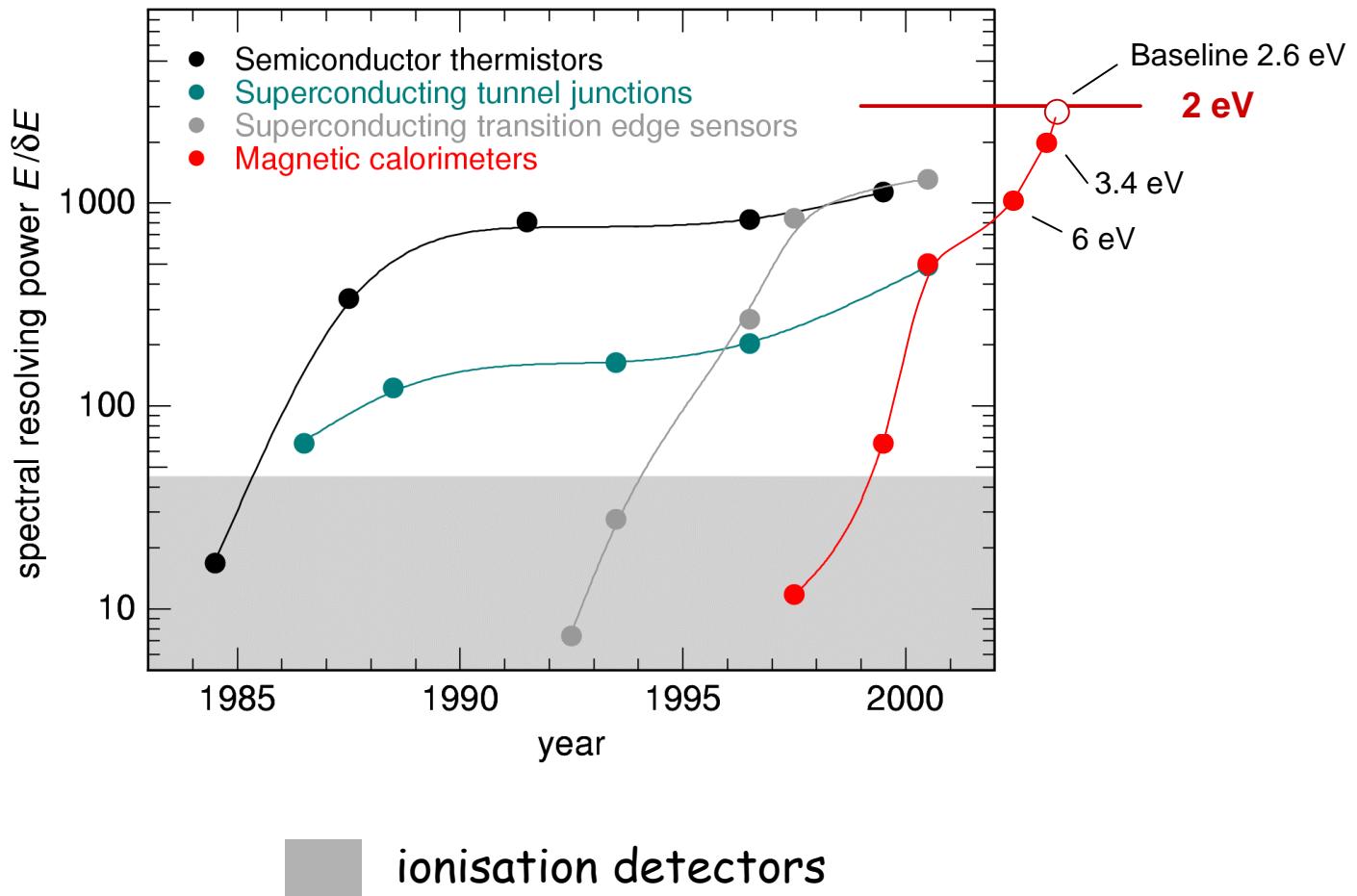
temperature independent

magnetic field independent
up to 3 mT

origin is unclear



E/dE at 6 keV



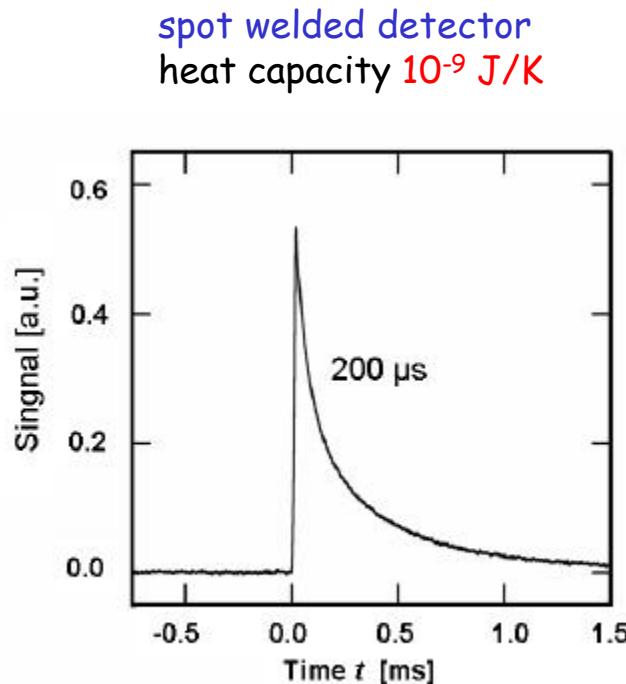
MMC Detectors for X Ray Astronomy

increase detector speed

not a problem

micro-fabrication of MMCs

a problem, but likely to be solvable

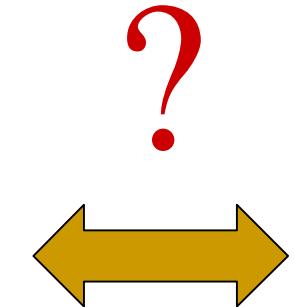


schemes for arrays and multiplexing

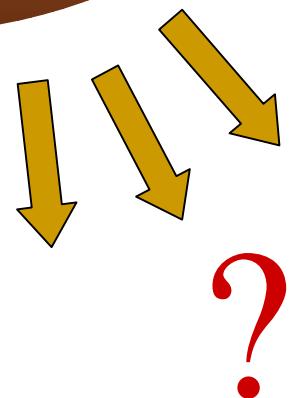
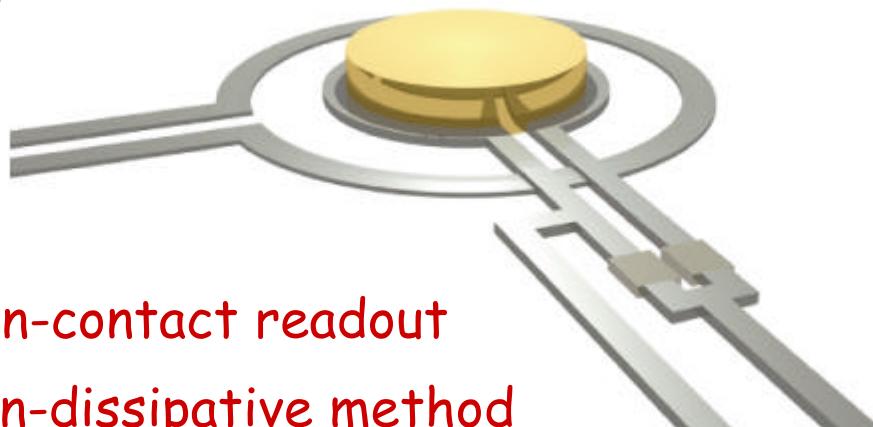
a very complex problem

MMC Arrays for X Ray Astronomy

- speed
- cross talk
- efficiency
- homogeneity
- power dissipation
- signal to noise
- complexity
- stability



- coupling schemes
- fabrication techniques
- layout and wiring schemes
- signal analysis schemes
- readout schemes



MMC specific : non-contact readout
non-dissipative method

Informal Collaboration on MMCs for Astronomy



S. Romaine
R. Bruni



Goddard

S.R. Bandler
T.R. Stevenson
F.S. Porter
E. Figueroa-Feliciano
C.K. Stahle
R. Kelley



Boulder

K.D. Irwin
B.L. Zink
G.C. Hilton
D.P. Pappas
J.N. Ullom
M.E. Huber, Uni. Colorado



G.M. Seidel
Y.H. Kim
Y.H. Huang
H. Eguchi
C. Enss



Heidelberg

A. Fleischmann
M. Linck
T. Daniyarov
H. Rotzinger
A. Burg



Berlin

J. Beyer
D. Drung
T. Schurig



Jena

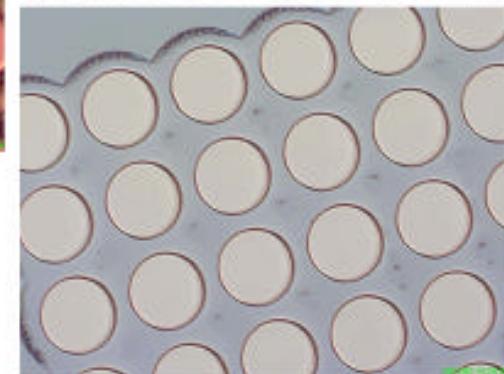
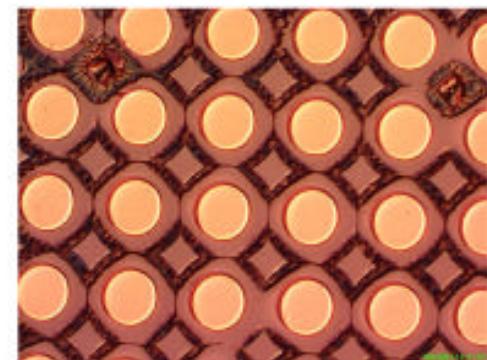
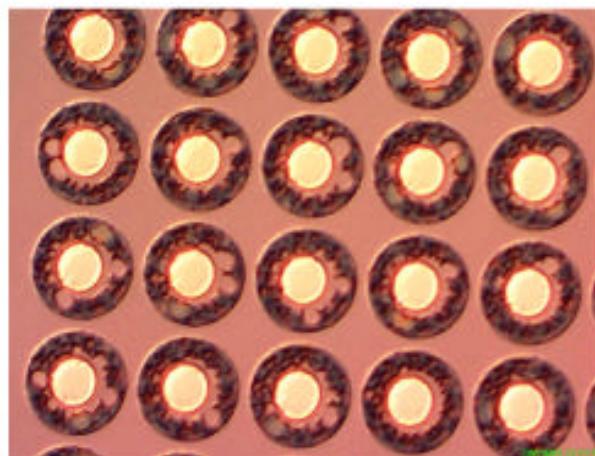
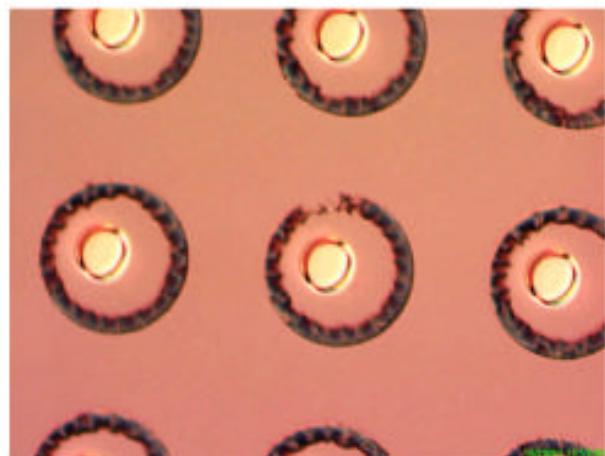
H.-G. Meyer
R. Stolz
S. Zarisarenko

SAO

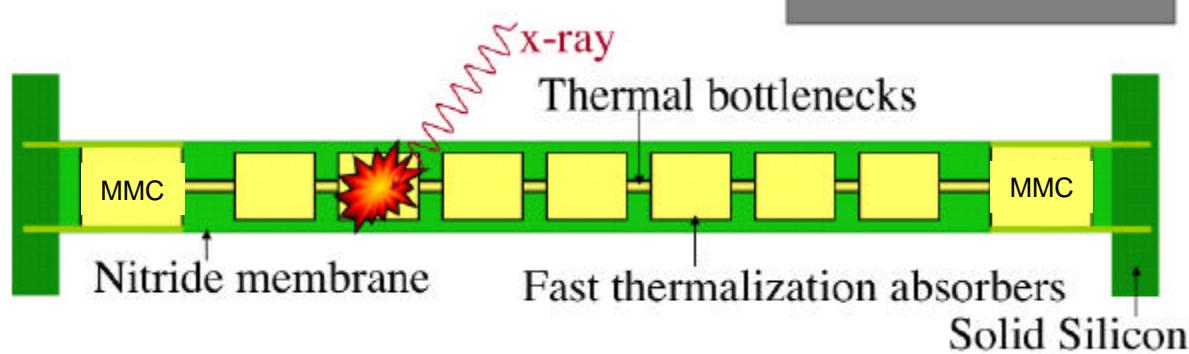
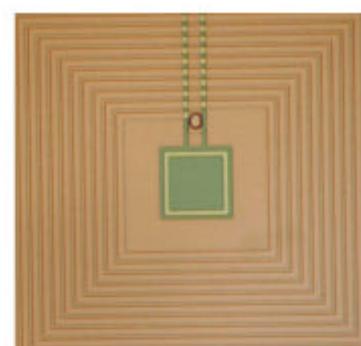
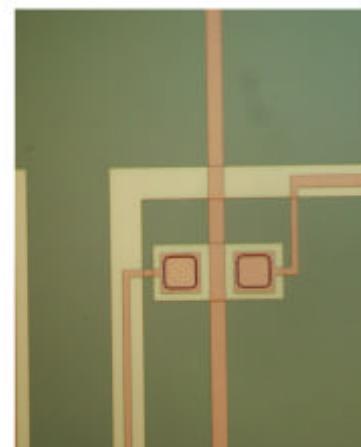
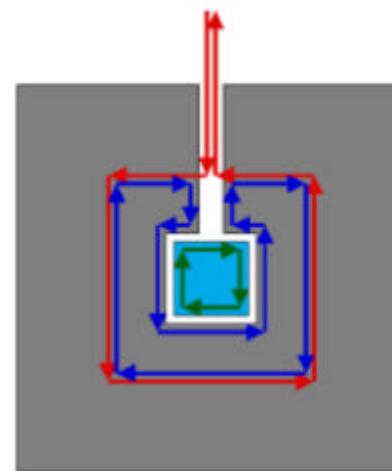
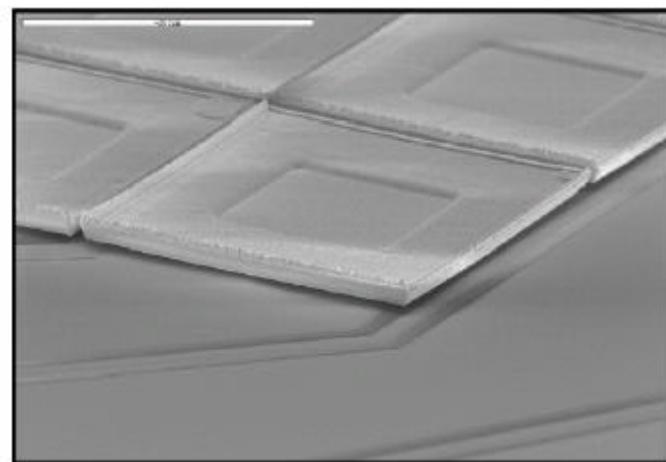
development of deposition techniques for Au:Er

integrate Au:Er sensors on SQUID chips

Some recently fabricated “mushroom” stems (thickness= 1-10 μm) :



development of suitable absorbers Bi:Cu
develop means of fabricating MMC mushrooms
investigating different transformer schemes
development of position sensitive MMCs



NIST Boulder

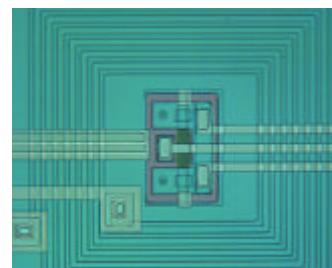
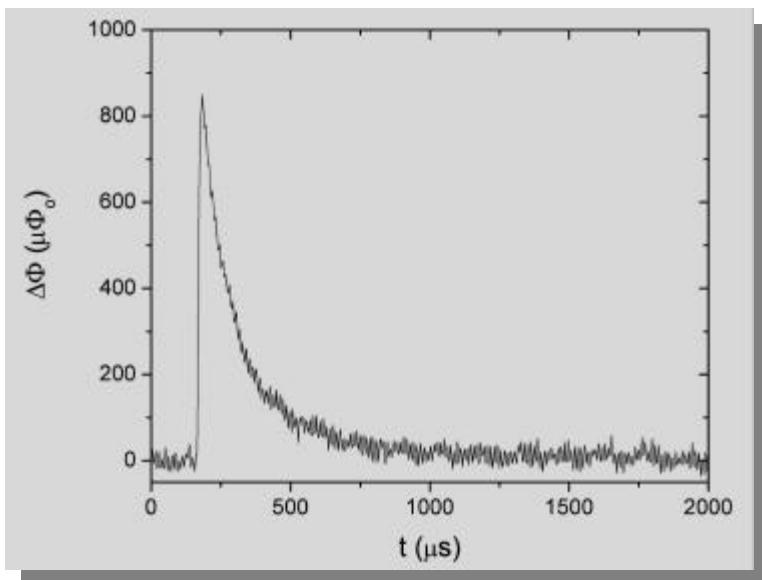
development of integrated MMCs

investigating new schemes for MMCs: self-inductance MMCs

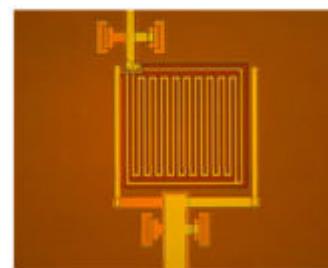
develop optimized SQUIDs

explore new multiplexing techniques

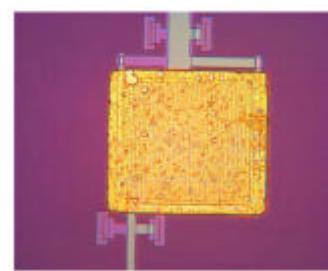
develop fabrication methods



Optimized
SQUID



Self-Inductance
Meander
Transformer

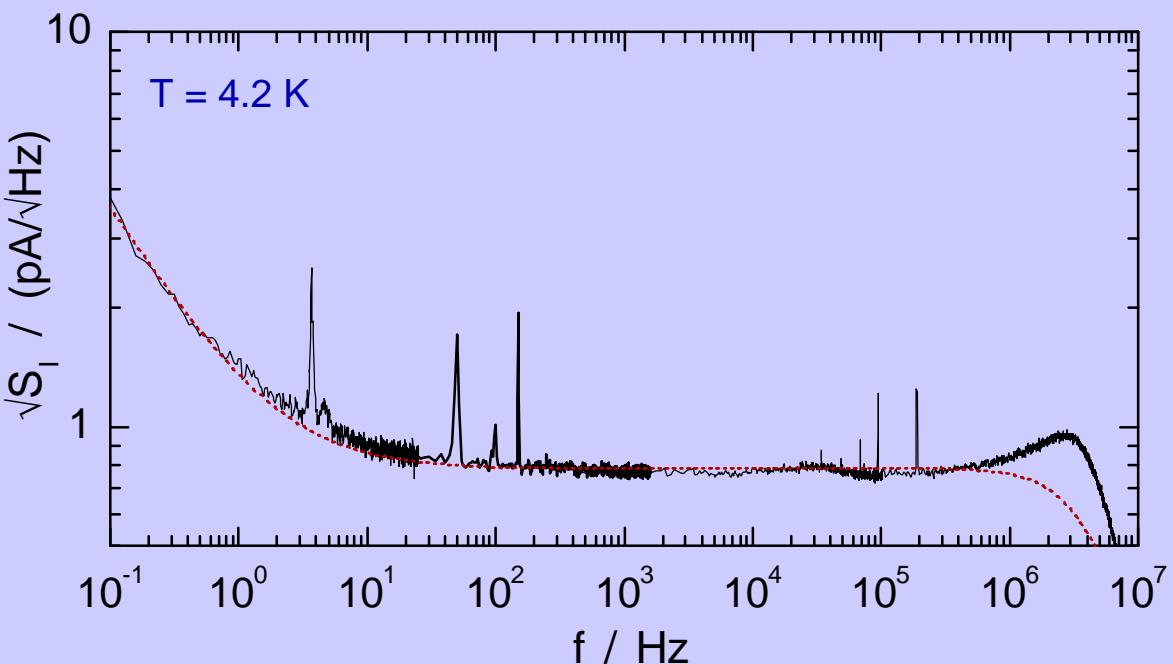
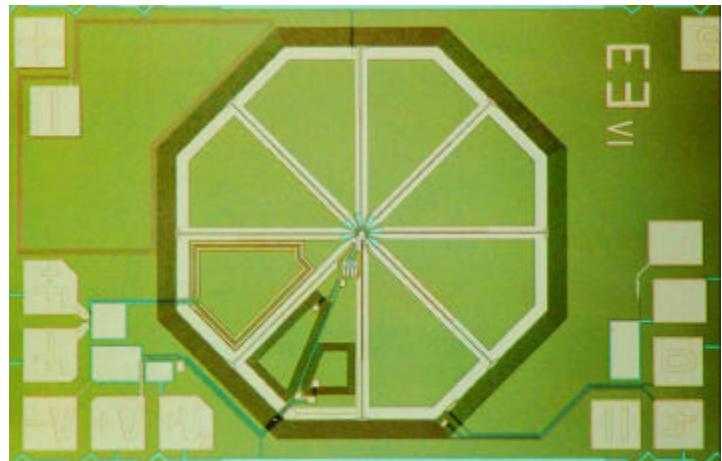


Co-evaporated
Au:Er Sensor
Film



development of optimized SQUIDs

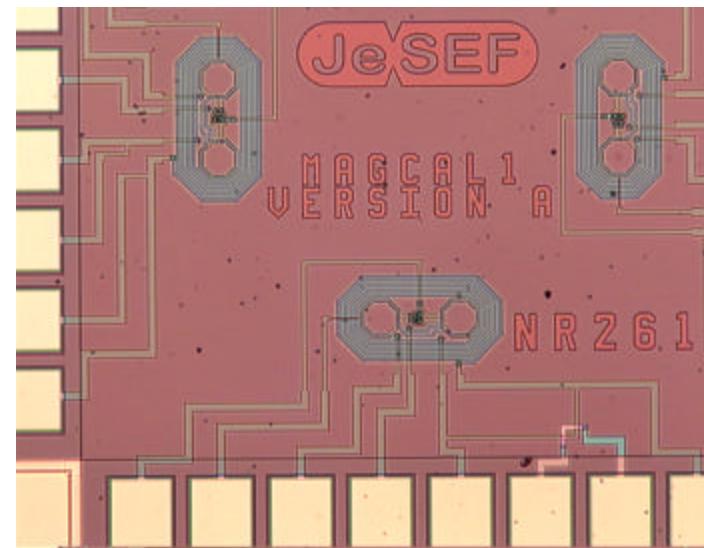
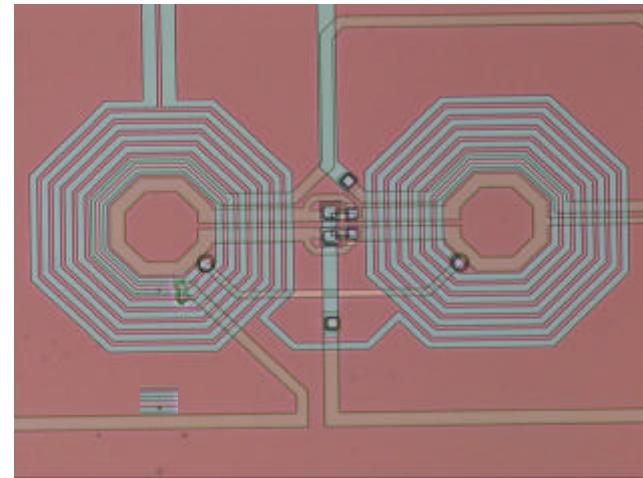
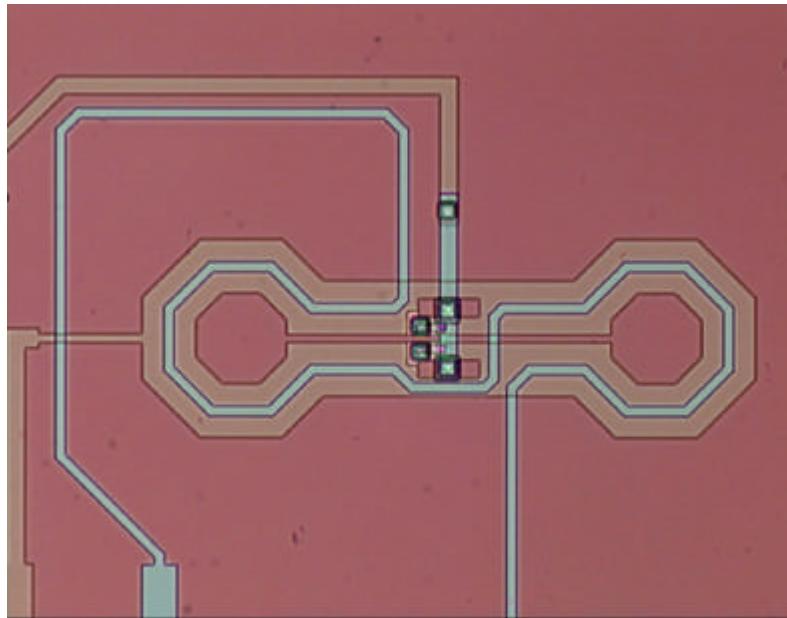
high speed low-noise readout electronics



development of optimized SQUIDs

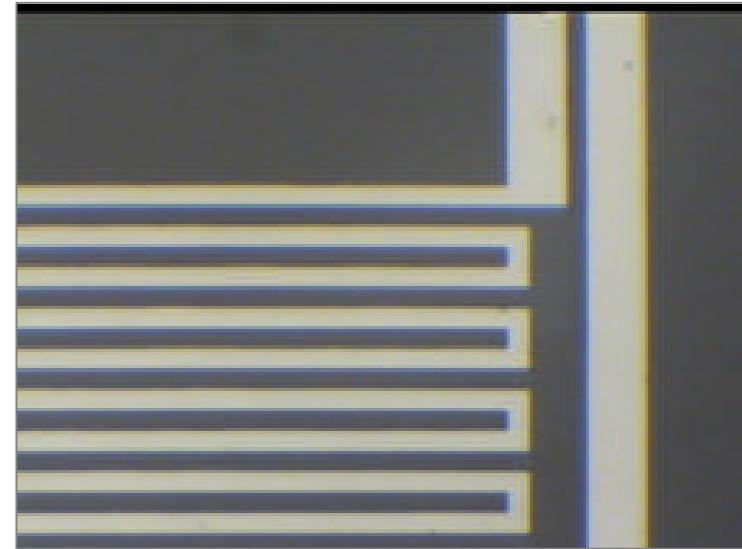
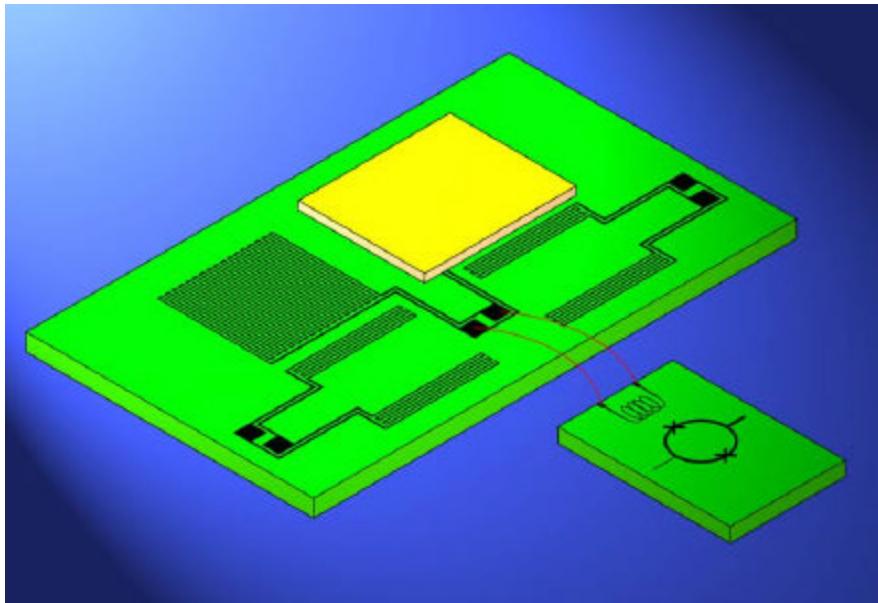
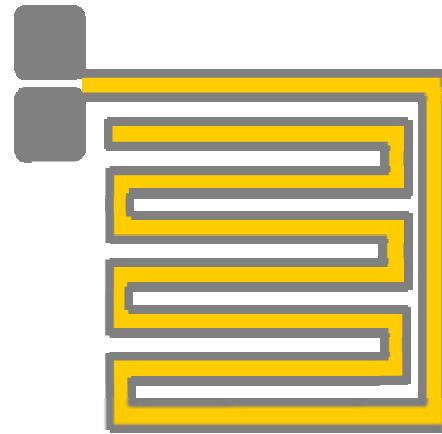
low noise readout electronics

optimized sensor design



Brown/Heidelberg

investigate alternative sensor materials
study $1/f$ noise
develop new sensor geometries
develop deposition techniques for Au:Er
optimize single pixel performance
study properties of small arrays



Summary

MMCs can be a new exciting tool for X-ray astronomy

SOHO 304 Å

Let's work to make it happen

Predicted Resolution for Different Detectors

Resolution:

$$\Delta E_{\text{FWHM}} \simeq 2.36 \sqrt{4k_B C_a T^2} \sqrt{2} \left(\frac{\tau_0}{\tau_1} \right)^{1/4}$$

Energy range: 1 ... 6 keV

$T = 50 \text{ mK}$, $t_0 = 10^{-6} \text{ s}$, $t_1 = 10^{-4} \text{ s}$

$250 \times 250 \times 8 \mu\text{m}^3$, Bi/Cu absorber

Au:Er 900 ppm sensor, $\varnothing 35 \mu\text{m}$, $h = 14 \mu\text{m}$

Energy range: 0.25 ... 0.6 keV

$T = 50 \text{ mK}$, $t_0 = 10^{-6} \text{ s}$, $t_1 = 10^{-4} \text{ s}$

$120 \times 120 \times 0.5 \mu\text{m}^3$, Bi/Cu absorber

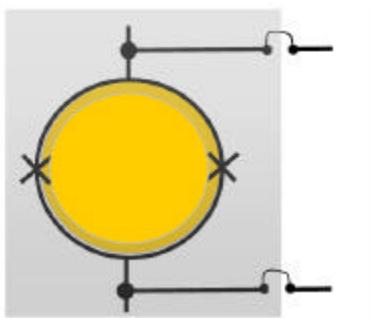
Au:Er 900 ppm sensor, $\varnothing 20 \mu\text{m}$, $h = 8 \mu\text{m}$

$$\rightarrow \Delta E_{\text{FWHM}} = 0.7 \text{ eV}$$

$$\rightarrow \Delta E_{\text{FWHM}} = 0.1 \text{ eV}$$

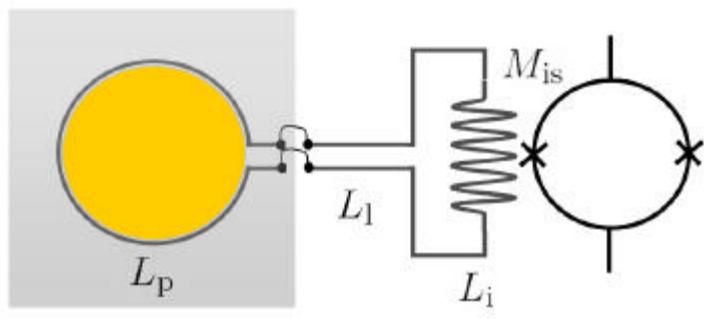
Possible Coupling Schemes

Direct Read Out



maximum signal, but complex fabrication and large power dissipation on chip

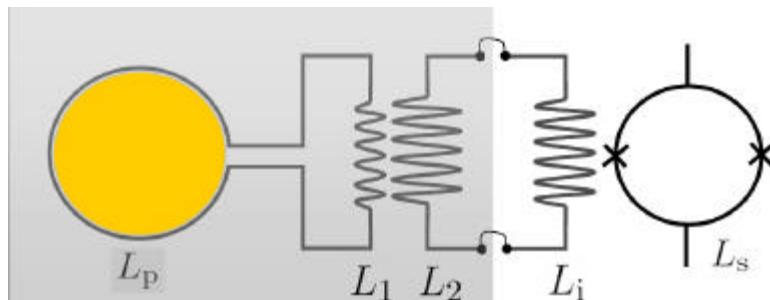
Fluxtransformer



simple wiring, no power dissipation on chip, but signal loss

$$\frac{\delta\Phi_s}{\delta\Phi_p} \approx \frac{M_{is}}{L_p + L_1 + L_i} < 0.5$$

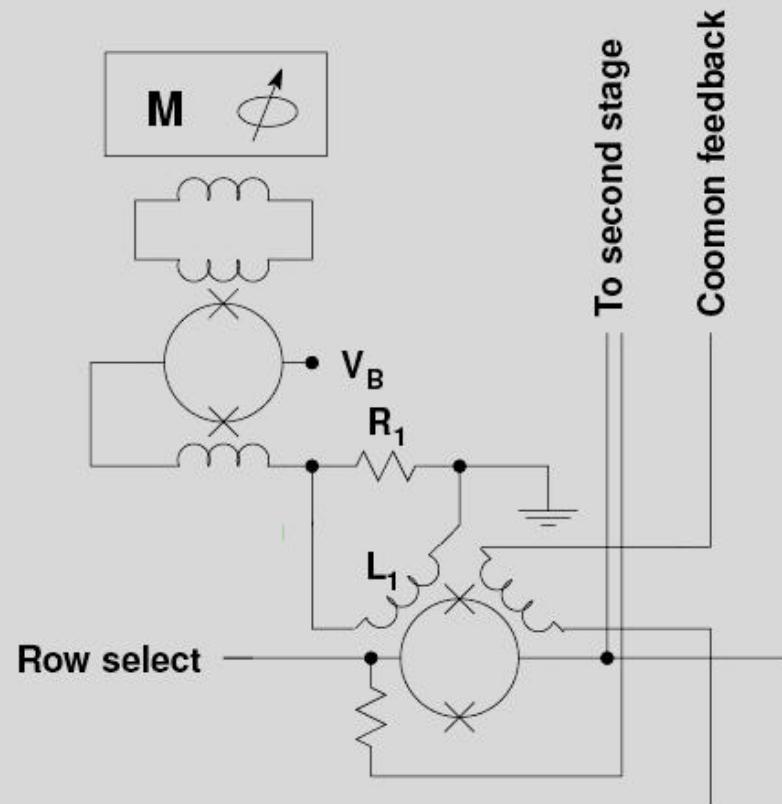
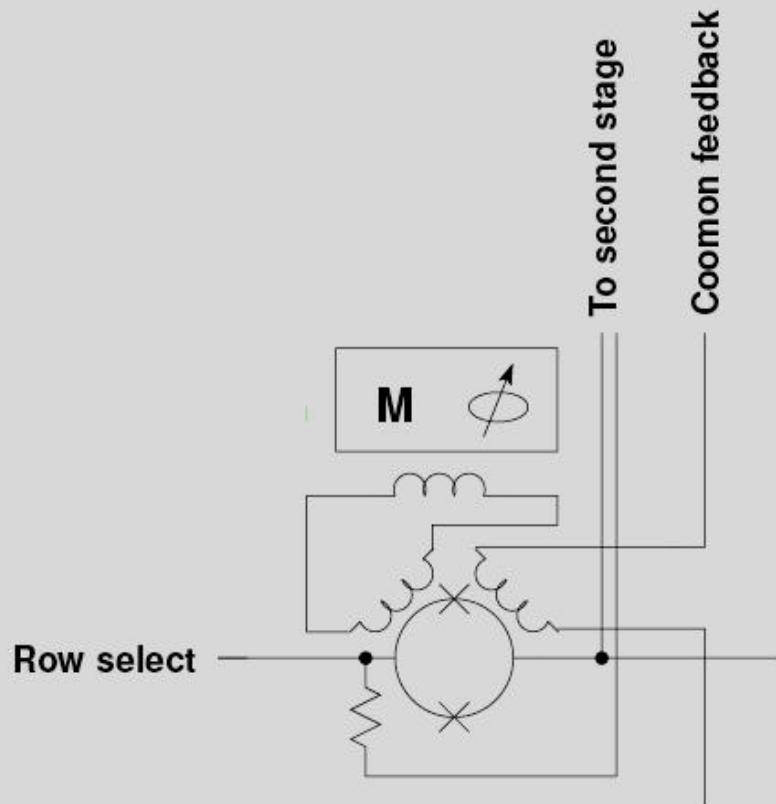
Step-up Transformer



simple wiring, no power dissipation on chip, but signal loss

$$\frac{\delta\Phi_s}{\delta\Phi_p} \approx 0.35 \sqrt{\frac{L_s}{L_p}}$$

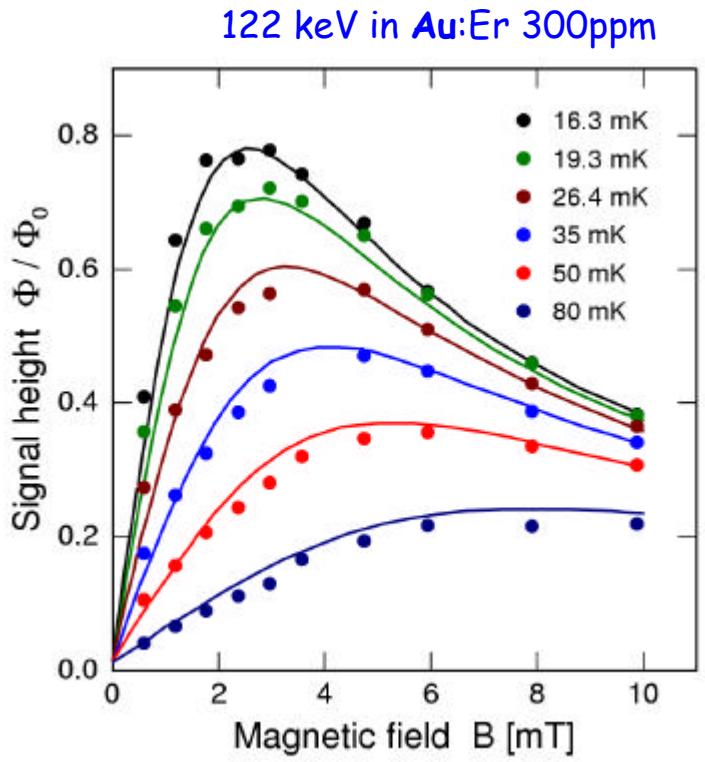
New Multiplexing Schemes



Calorimeter Signal

$$\delta\Phi_S = f(r, h) \frac{\partial M}{\partial T} \frac{1}{C_{\text{tot}}} \delta E$$

- satisfying **agreement** of theory and experiment
- signal size can be **predicted!**

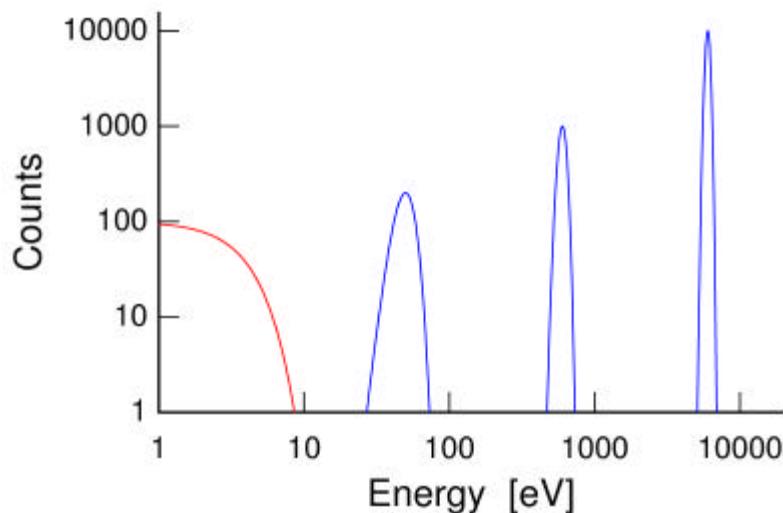


Resolution of optimized detector:

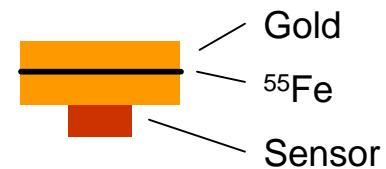
$$\Delta E_{\text{FWHM}} \simeq 2.36 \sqrt{4k_B C_a T^2} \sqrt{2} \left(\frac{\tau_0}{\tau_1} \right)^{1/4}$$

Absolute Dosimetry

goal: measurement of absolute source activity
example ^{55}Fe

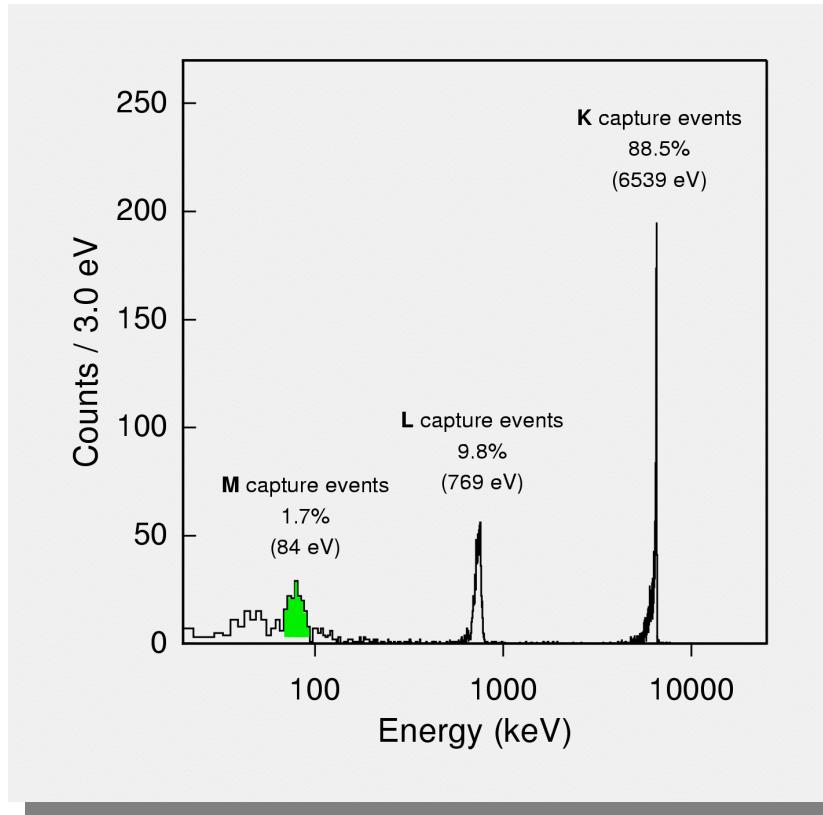


4π -Sandwich:



COMMISSARIAT À L'ÉNERGIE ATOMIQUE

Preliminary Result



M. Loidl, E. Leblance, J. Bouchard, T. Branger,
N. Coron, J. Leblanc, P. de Marcillac, H. Rotzinger,
T. Daniyarov, M. Linck, A. Fleischmann, C. Enss,
Proceeding of ICRM 2003